Impacts and Mitigation of Dairy Feed on Air Quality

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Background

VOC Sources on Dairies

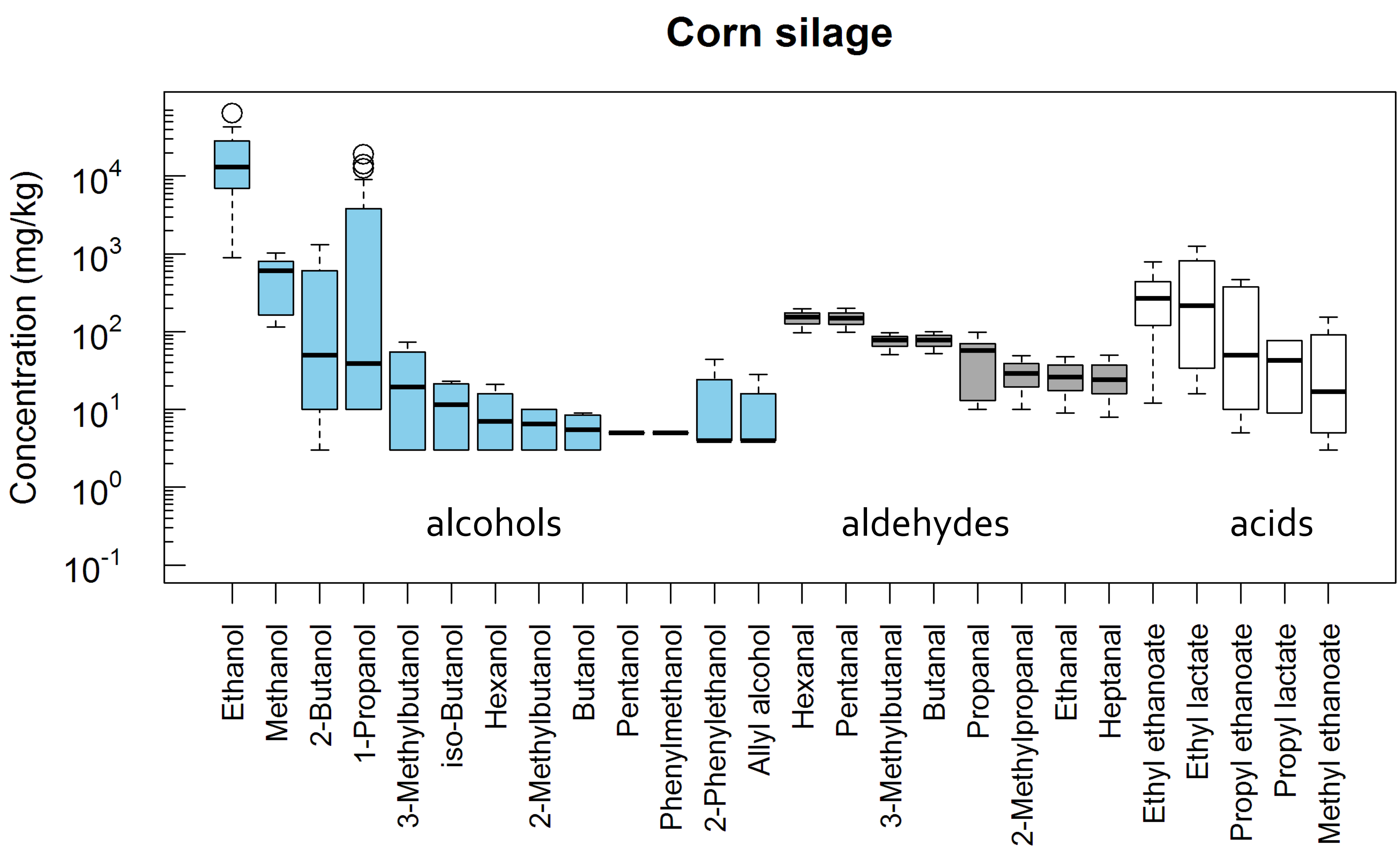
Manure in housing facility

Manure storage

Land application

Measurements on California dairies indicate that over 90% of the reactive VOC emissions come from silage sources

Silage VOCs



Hafner et al., 2013. “Emission of Volatile Organic Compounds from Silage: Compounds, Sources, and Implications.” *Atmospheric Environment* 77 (October): 827–839.

Covering Corn Silage

Silage storage types

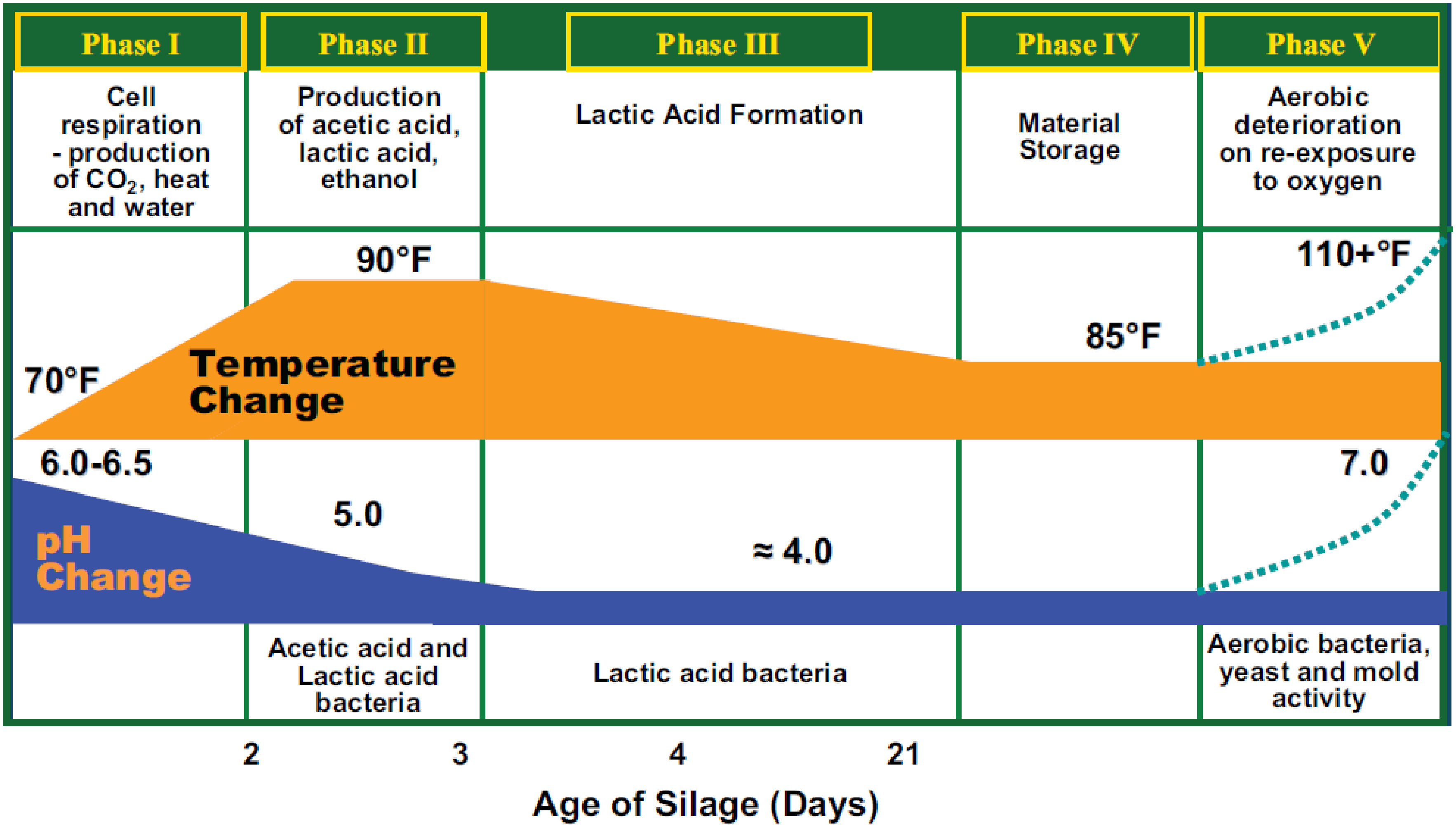
Conventional silage pile

Silage phases (after ensiling has occurred)

The VOCs and NOx gases are emitted during the distinct phases of the silage/feeding process, which include:

- The aerobic phase: when chopped material is piled, compacted, and covered,
- The fermentation phase: when silage material is sealed and fermented,
- The storage phase: when silage material is sealed and few emissions released,
- The feed-out phase: during which silage material is removed from the face daily,
- The daily mixing phase: when silage is mixed with other feedstuffs in a mixer wagon, and
- The daily feeding phase: during which feed is placed in the feed lanes.

Phases of silage making



Corn Silage Dry Matter (DM) Losses

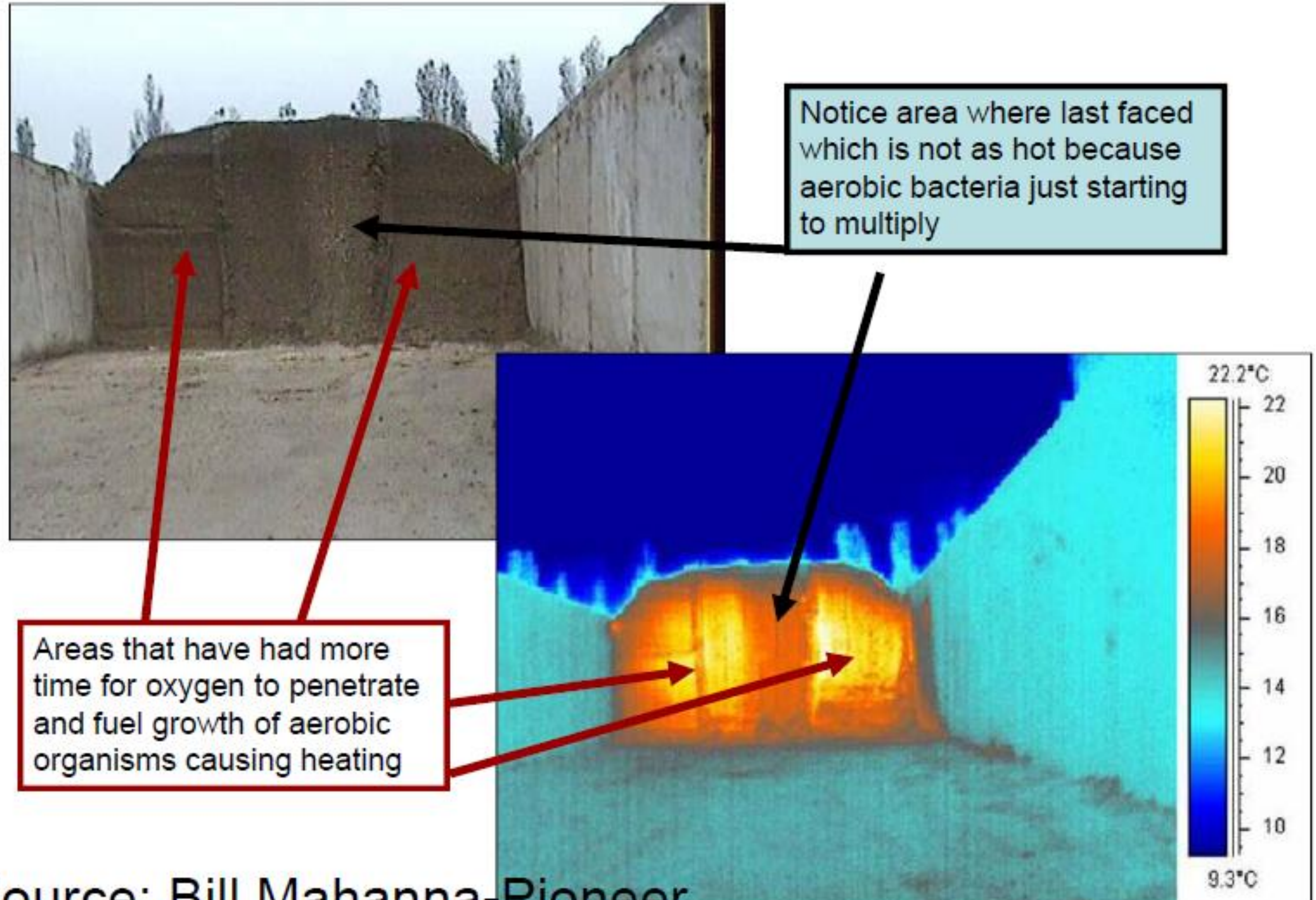
Residual Respiration	U	1 -> 4	O2 & plant enzymes
Fermentation	U	2 -> 6	Microorganisms
Effluent	A	0 -> 5	Low DM
Secondary Fermentation	A	0 -> 5	Silo & DM
Aerobic spoilage in storage	A/U	1 -> 10	Silo, density & sealing
Aerobic spoilage at feedout	A/U	1 -> 10	Feedout management

U: Unavoidable
A: Avoidable

DM losses (%)	Excellent	Average	Poor
Total	8-10%	11-15%	20-40%

(Zimmer, 1980; Adapted by Bolsen)

Silage gas during first 5 hrs of ensiling



Source: Bill Mahanna-Pioneer

Silage packing affects emissions

Objectives

- Measure emissions of VOCs from various defacing methods
- Measure emissions of VOCs from storage types
- Measure emissions of VOCs from TMR treated with water vs raw silage
- To use emission data measured on the commercial farms to refine and evaluate our silage VOC emission model

Emission Monitoring

Monitoring Equipment

- The Mobile Agricultural Air Quality Laboratory (MAAQ Lab) measured ethanol, methanol, ammonia, NO, N_2O, NO_2, and methane.
- 1. An automatic control and data acquisition system,
- 2. An automatic gas sampling system,
- 3. An infrared photo-acoustic multi-gas INNOVA 1412 analyzer,
- 4. A TEI 55C methane and non-methane hydrocarbon analyzer,
- 5. A TEI 17i NH3 analyzer,
- 6. A TEI 46i N_2O analyzer.
- 7. Four flux chambers,
- 8. Two wind tunnels,
- 9. An Environics 4040 Gas dilution system.

Setup/equipment

Setup/equipment

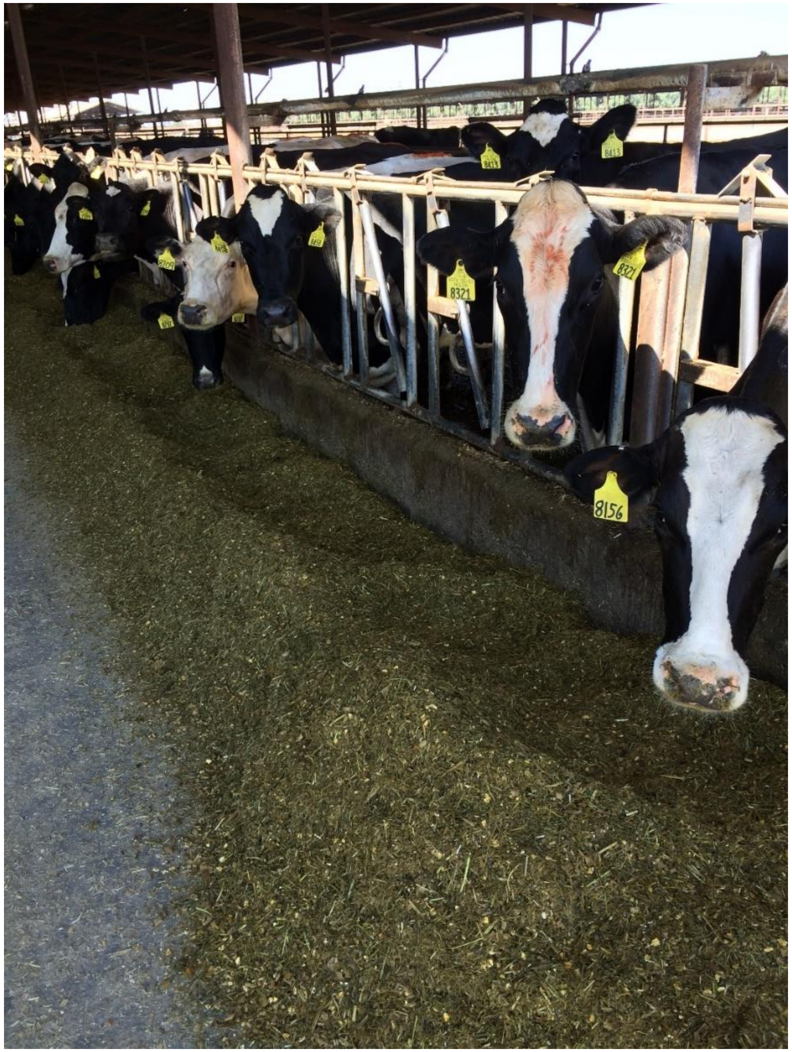
Perpendicular defacing

Lateral Defacing

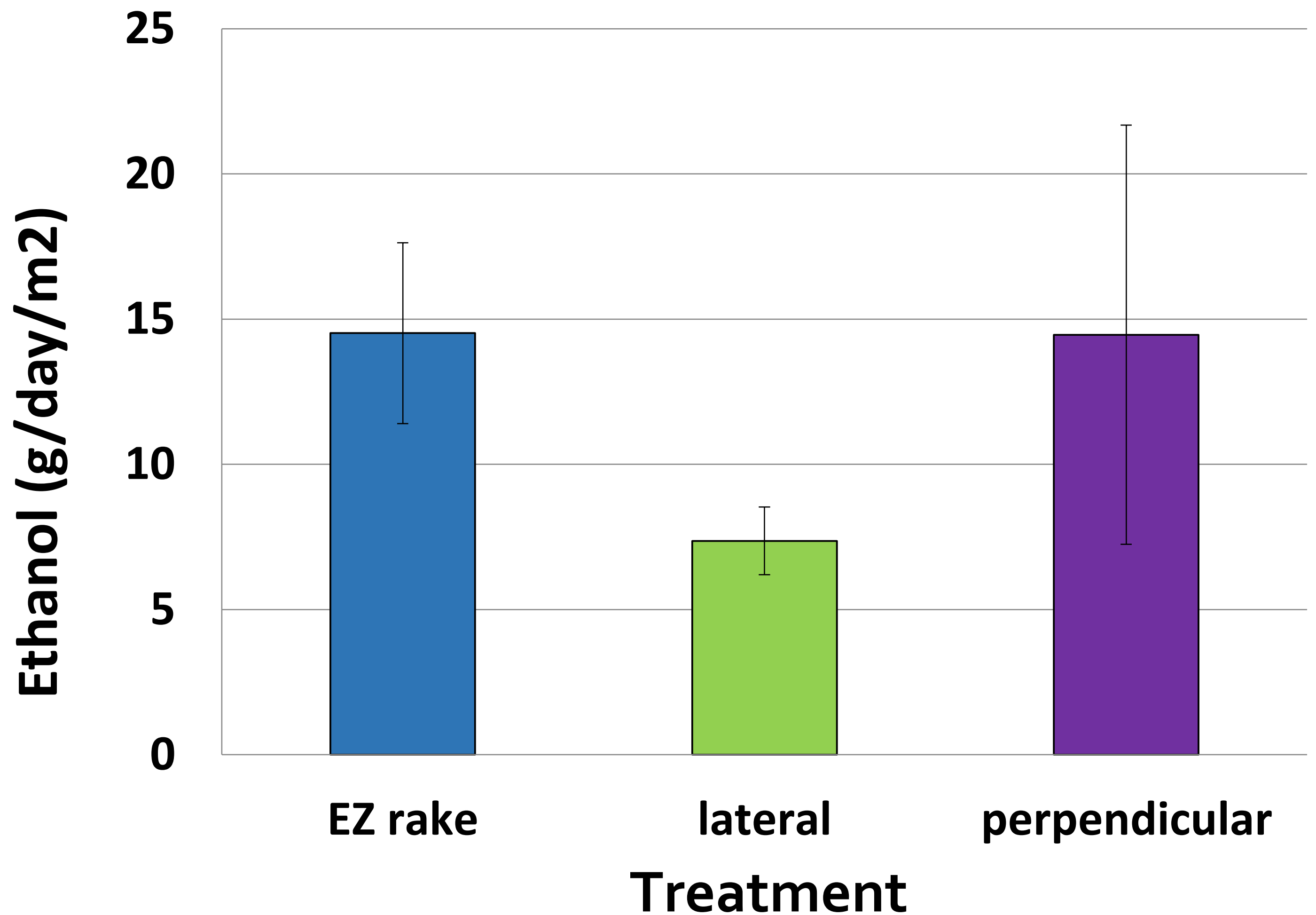
EZ Rake

Water Inclusion to TMR

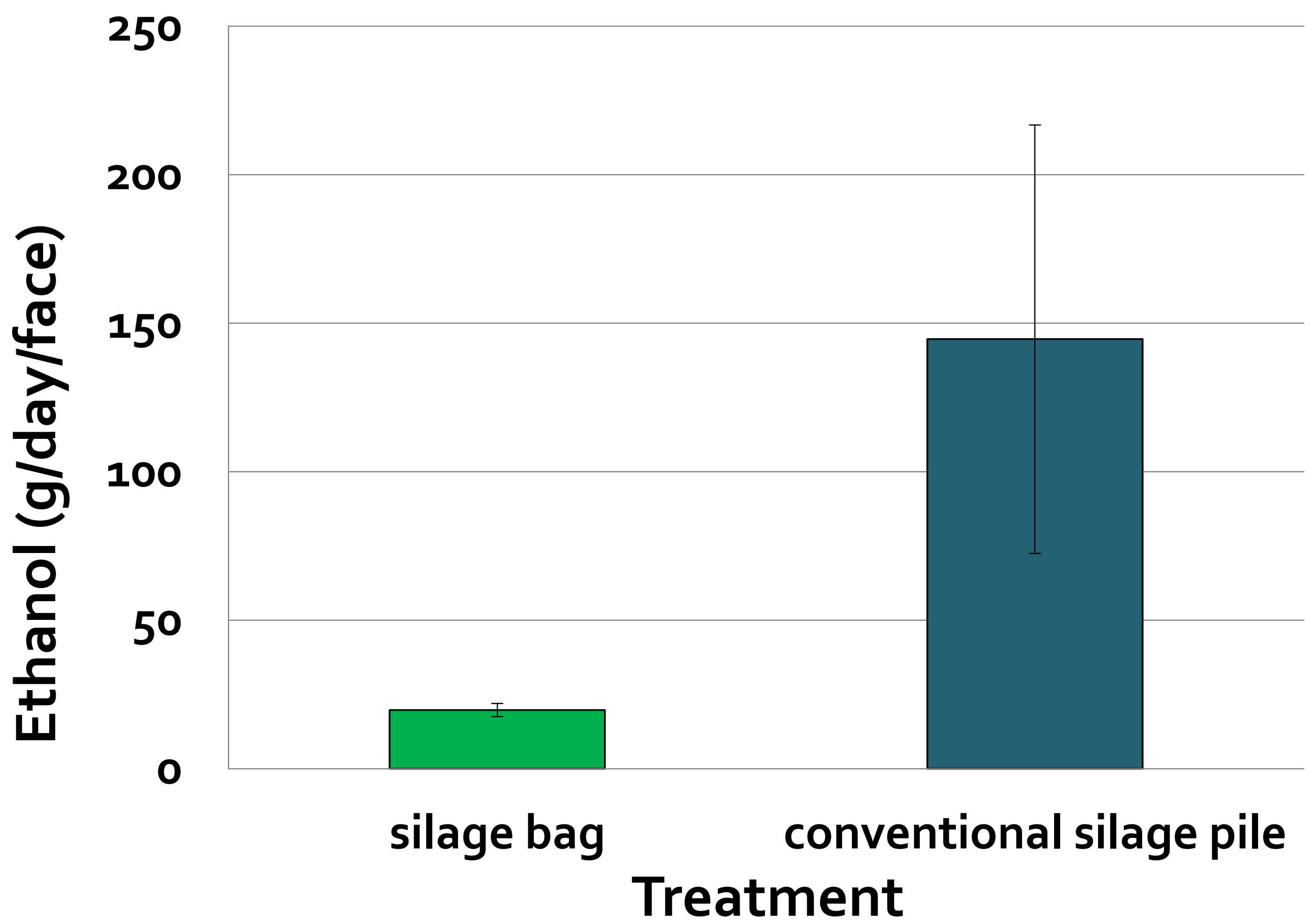
Feedlane



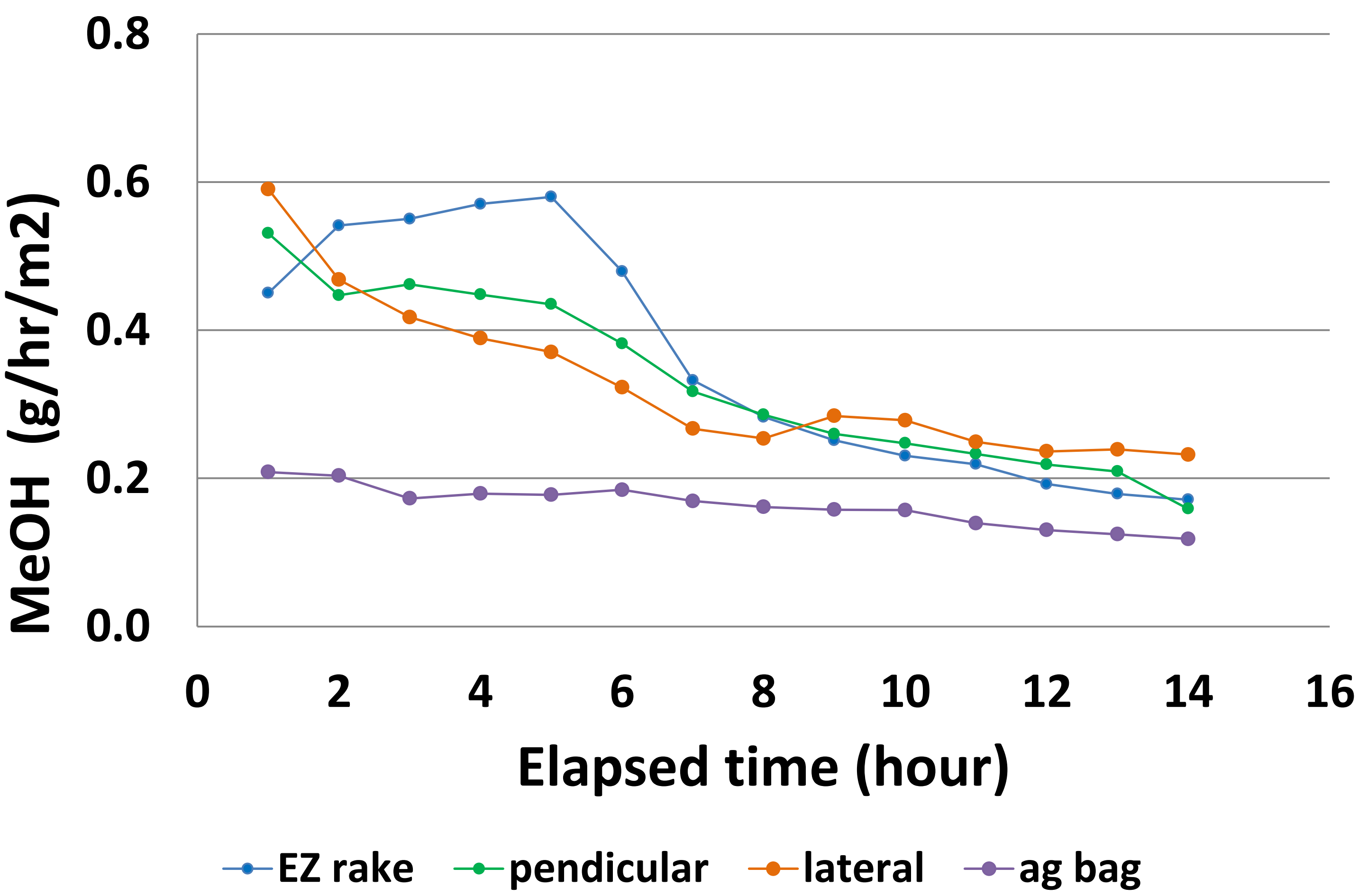
Ethanol (EtOH) emissions from different silage defacing methods



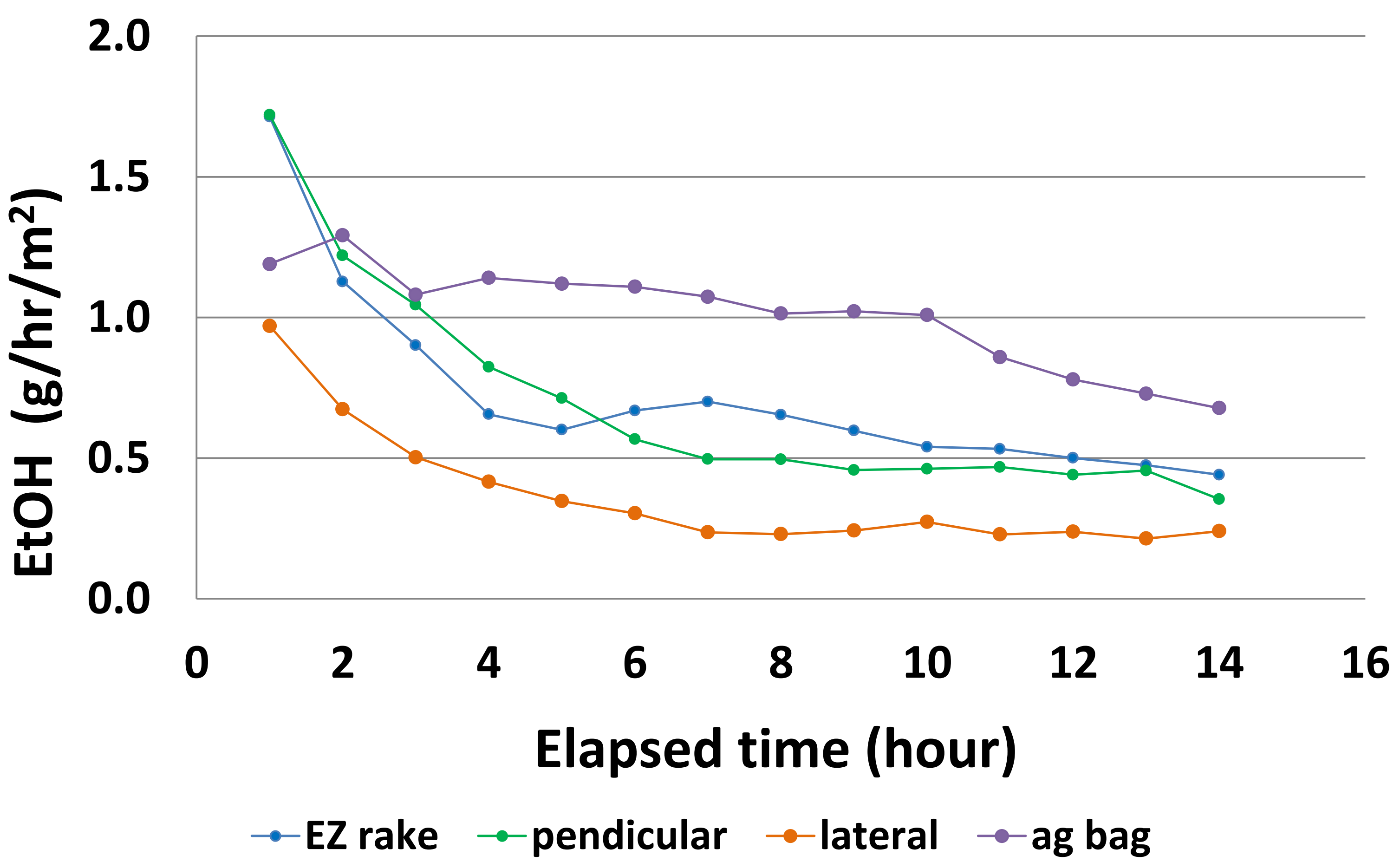
Ethanol (EtOH) emissions from silage storage methods



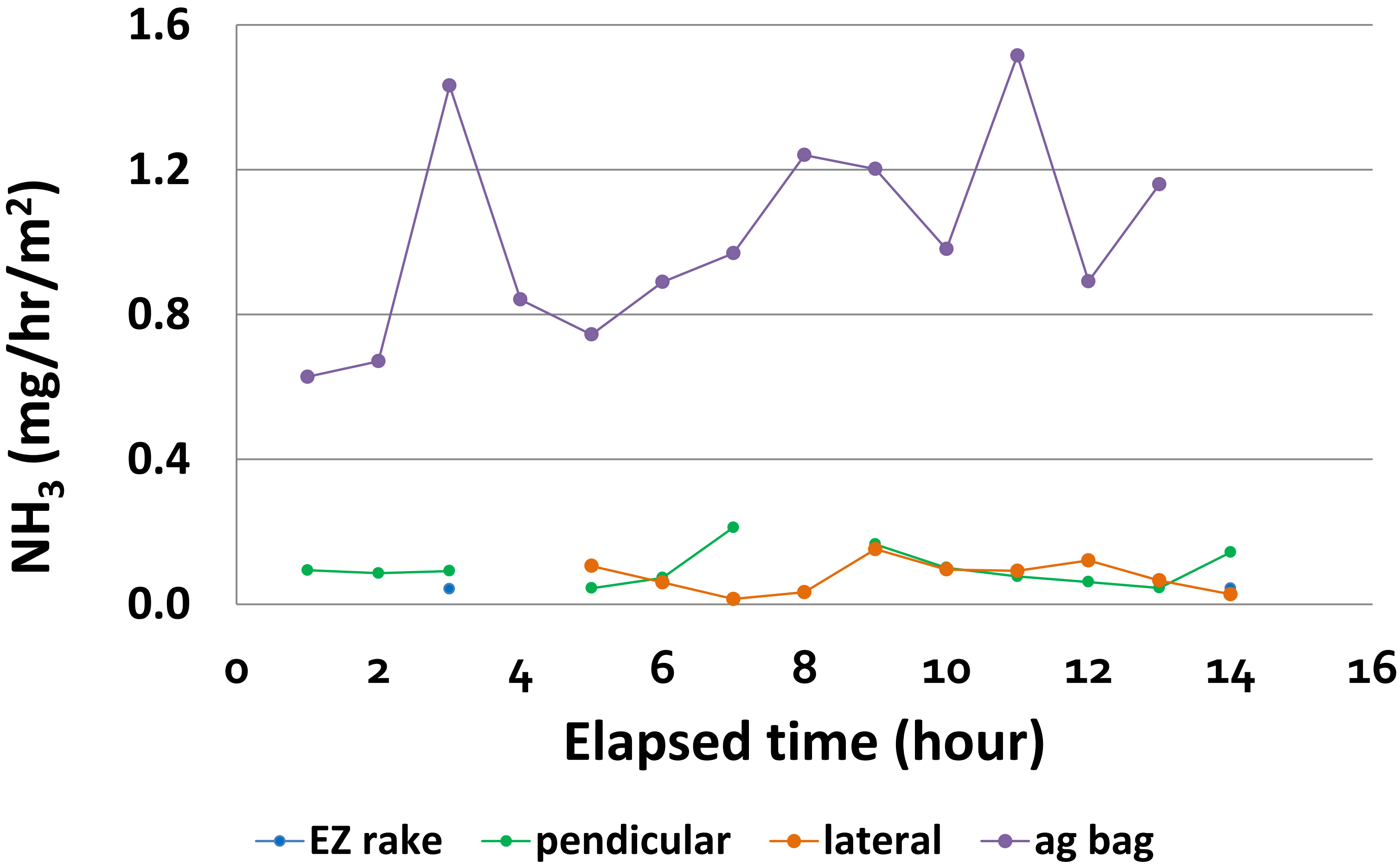
Methanol (MeOH) emissions from silage storage methods



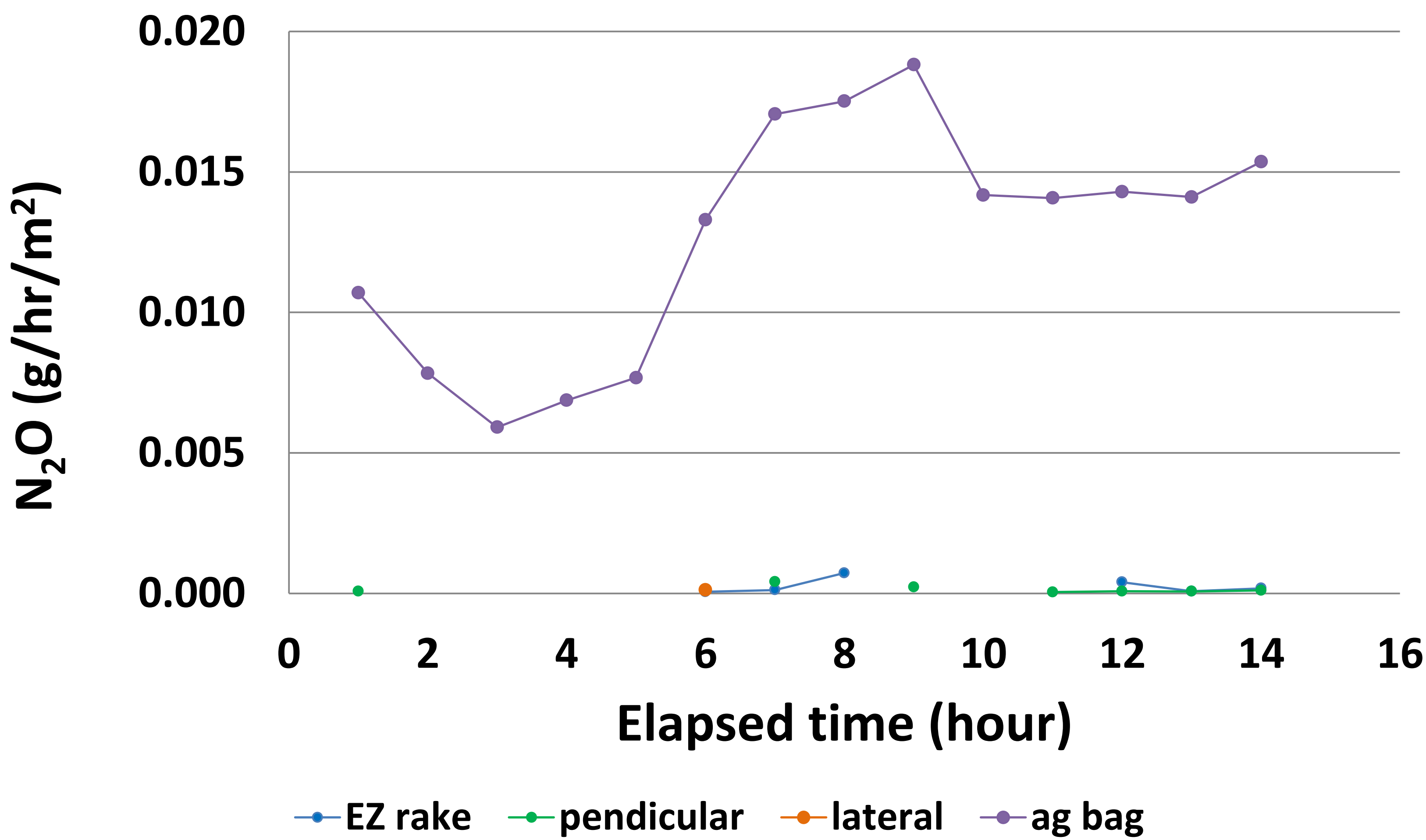
Ethanol (EtOH) emissions from silage storage methods



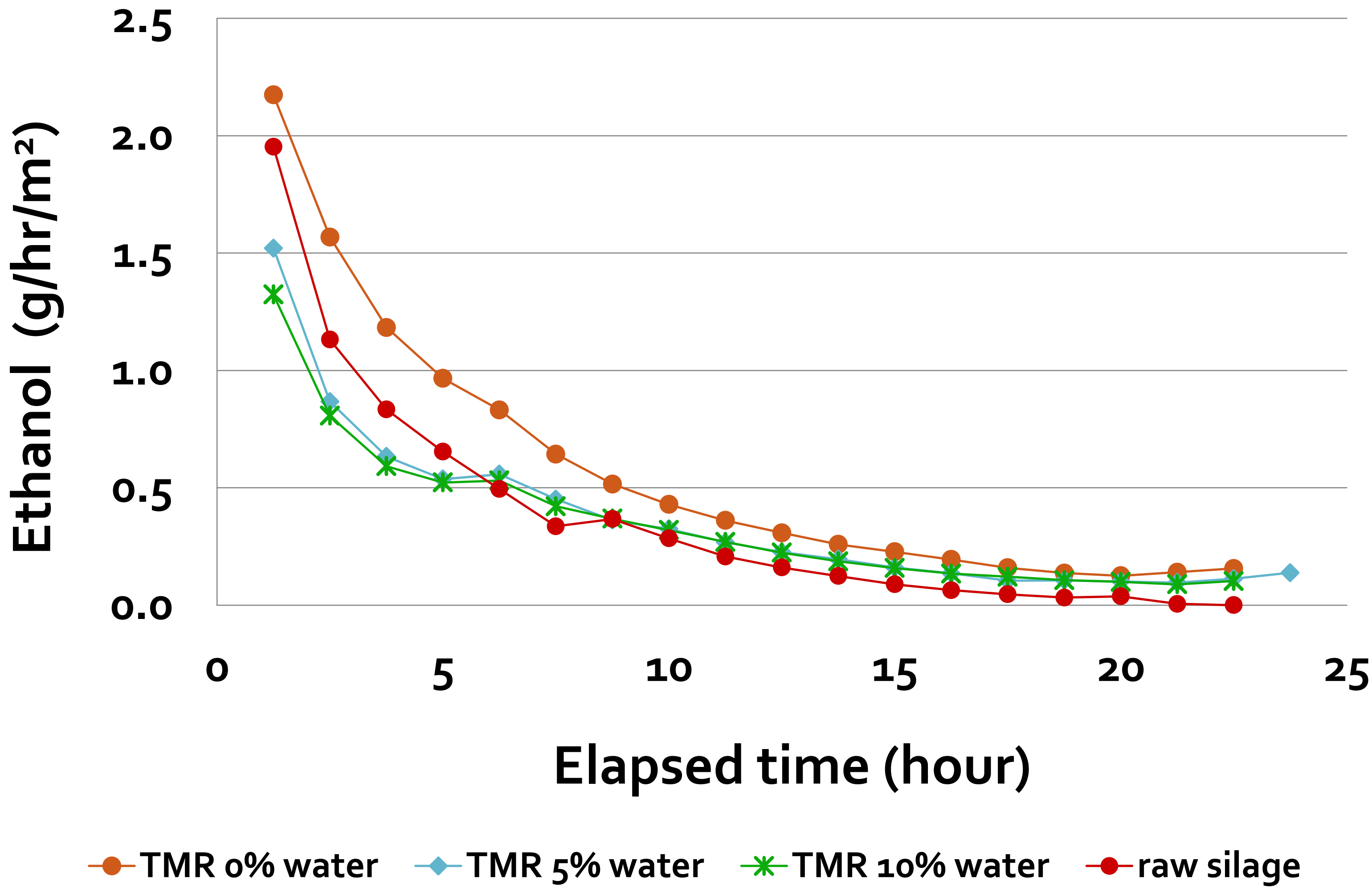
Ammonia (NH_3) emissions from silage storage methods



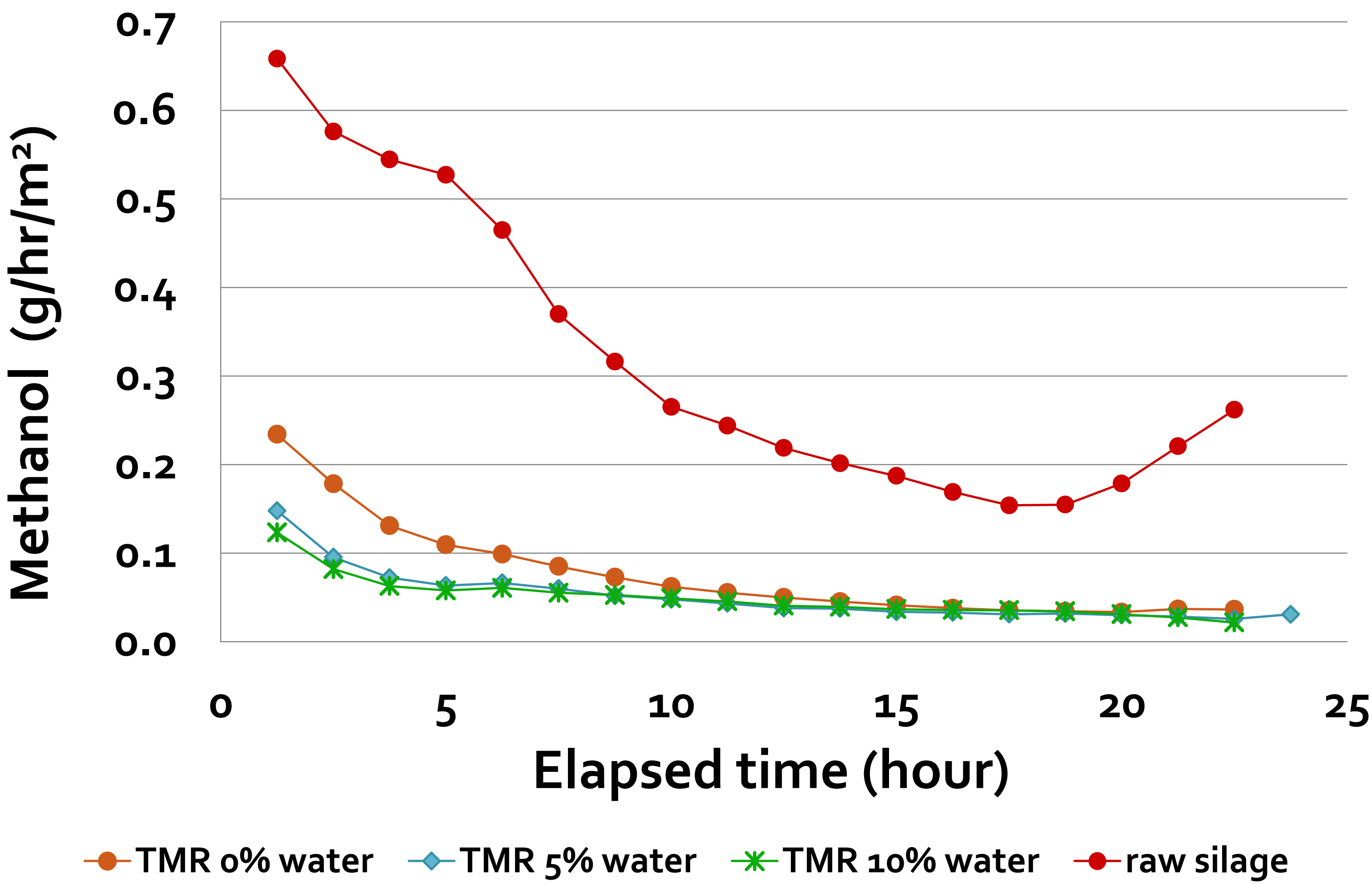
Nitrous oxide (N_2O) emissions from silage storage methods



Ethanol (EtOH) emissions from different TMR water inclusion rates



Methanol (MeOH) emissions from different TMR water inclusion rates

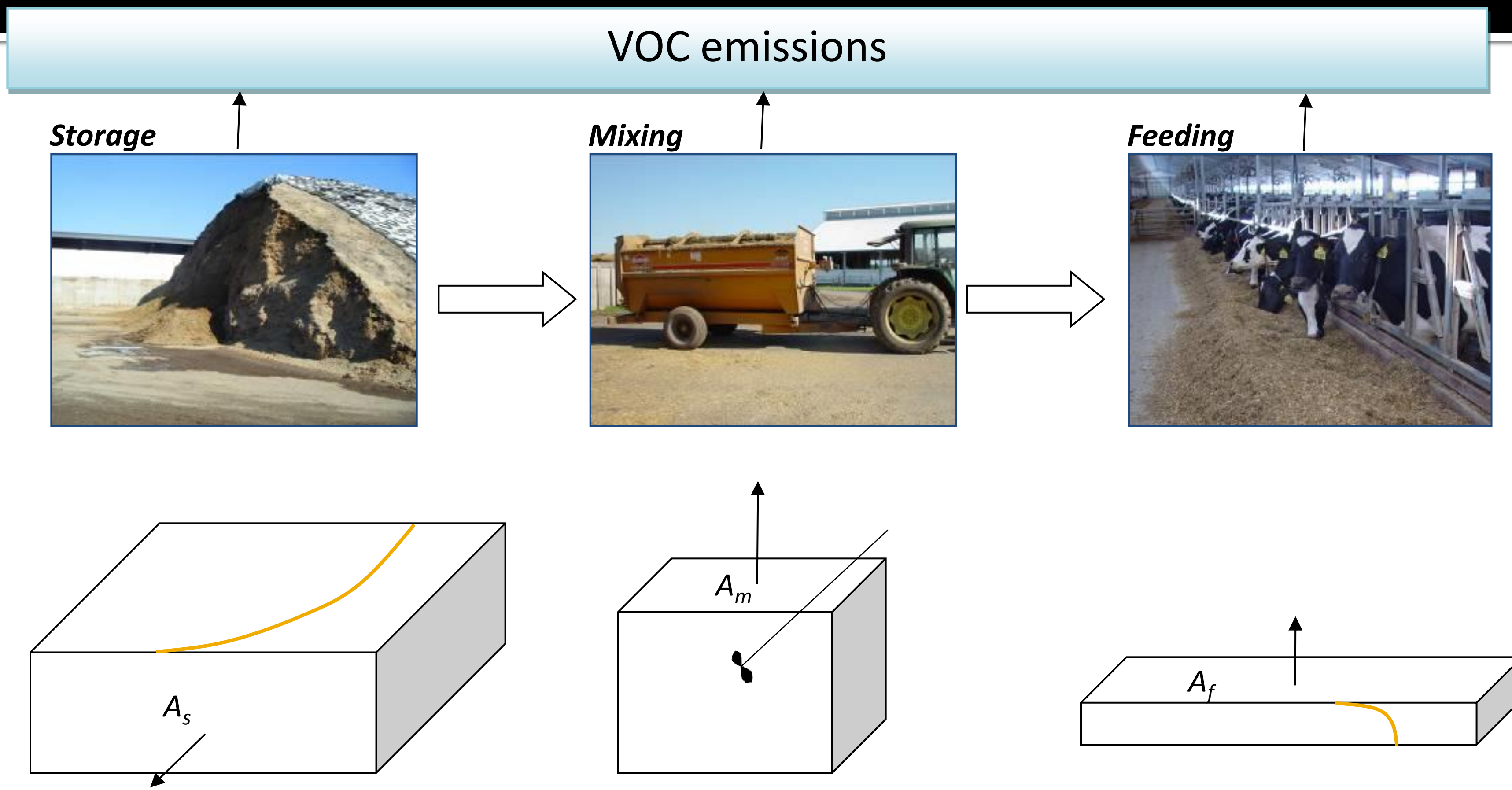


Emission Modeling

Modeling Objectives

- Develop a process-based model for predicting VOC emissions from silage
- Integrate that model into our whole farm simulation model (IFSM)
- Demonstrate the use of the model in evaluating whole-farm effects of silage management on environmental and economic impacts

Farm-level silage model concept



Convection-diffusion model

First-order model (completely mixed)

Convection-diffusion model

Model Evaluation

- **Ethanol and methanol emissions were measured from silage piles, silage bags and feed lanes on California dairies**
- **Simulated emissions were compared to measured data to more fully evaluate model performance**



Daily Emissions of Ethanol

Storage type	Defacing method	Measured (kg/d)	Simulated (kg/d)
Pile	Lateral	4.08	4.82
Pile	Perpendicular	7.91	7.82
Pile	Rake	8.00	7.51
Bag	---	0.89	0.21
Feed lane*	---	15.4	6.0

*Based upon 1,200 m^2 of feed lane area for 2,000 cows plus replacements

Model Application

Some example comparisons for a representative dairy farm in Central California

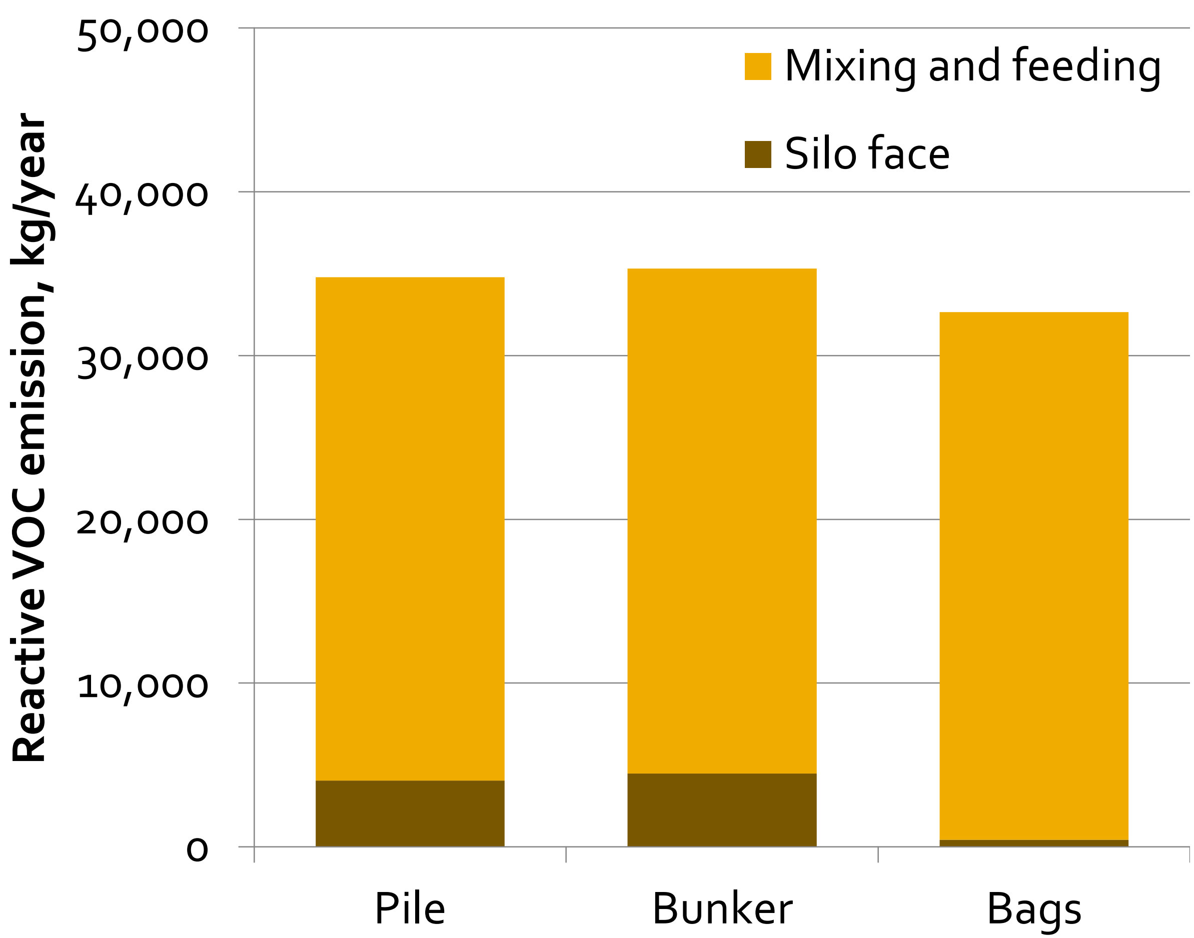
- 2,000 Holstein cows plus 1,650 replacement heifers
- 300 ha of clay loam soil
- Corn silage double cropped with winter small grain silage
- Free stall barn with open lot
- Cattle fed using total mixed rations
- Sacramento weather (1981-2005)

Management Comparisons

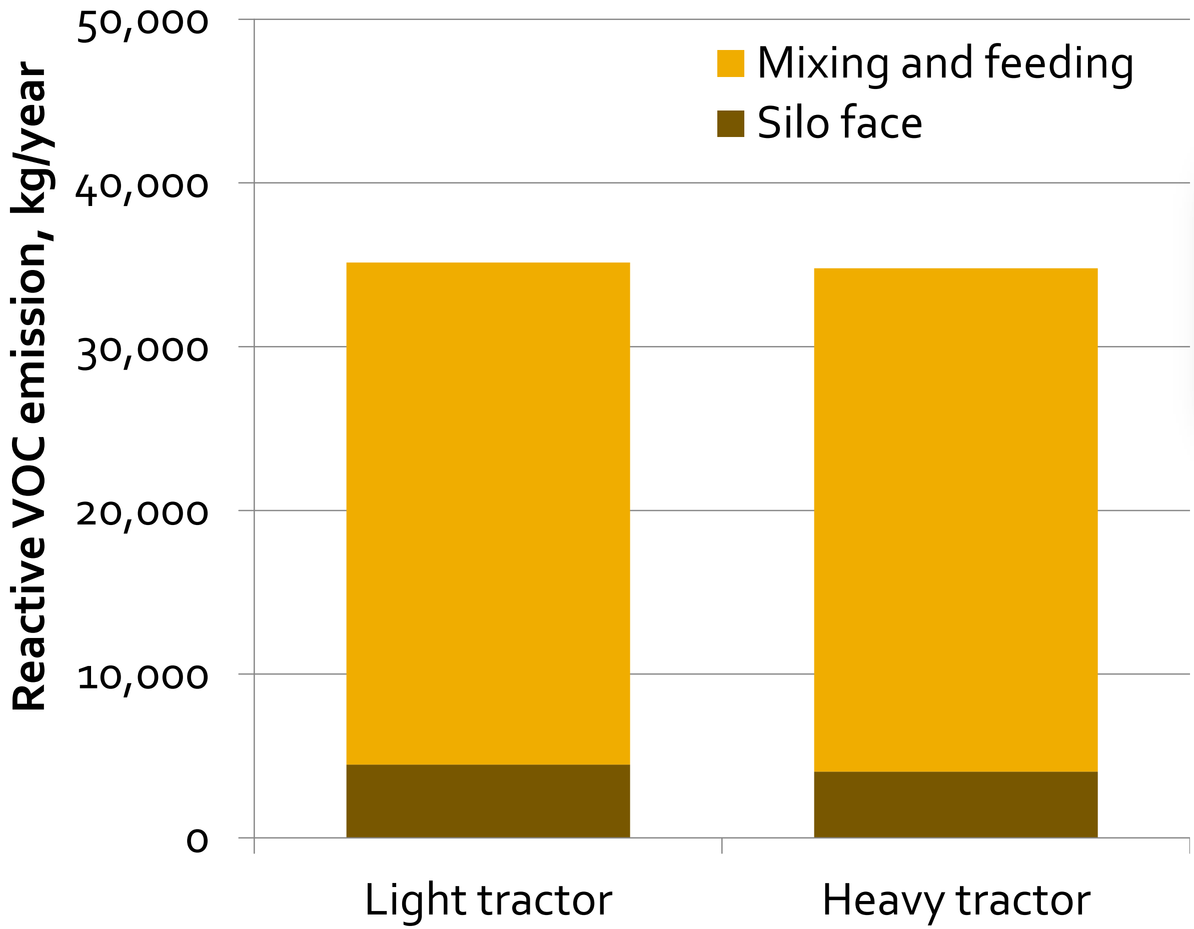
- Comparison of silo types (piles, bunker, bags)
- Silo unloading method
- Packing density (smaller packing tractor)
- Feeding site (open lot, enclosed barns)

Whole Farm Modeling

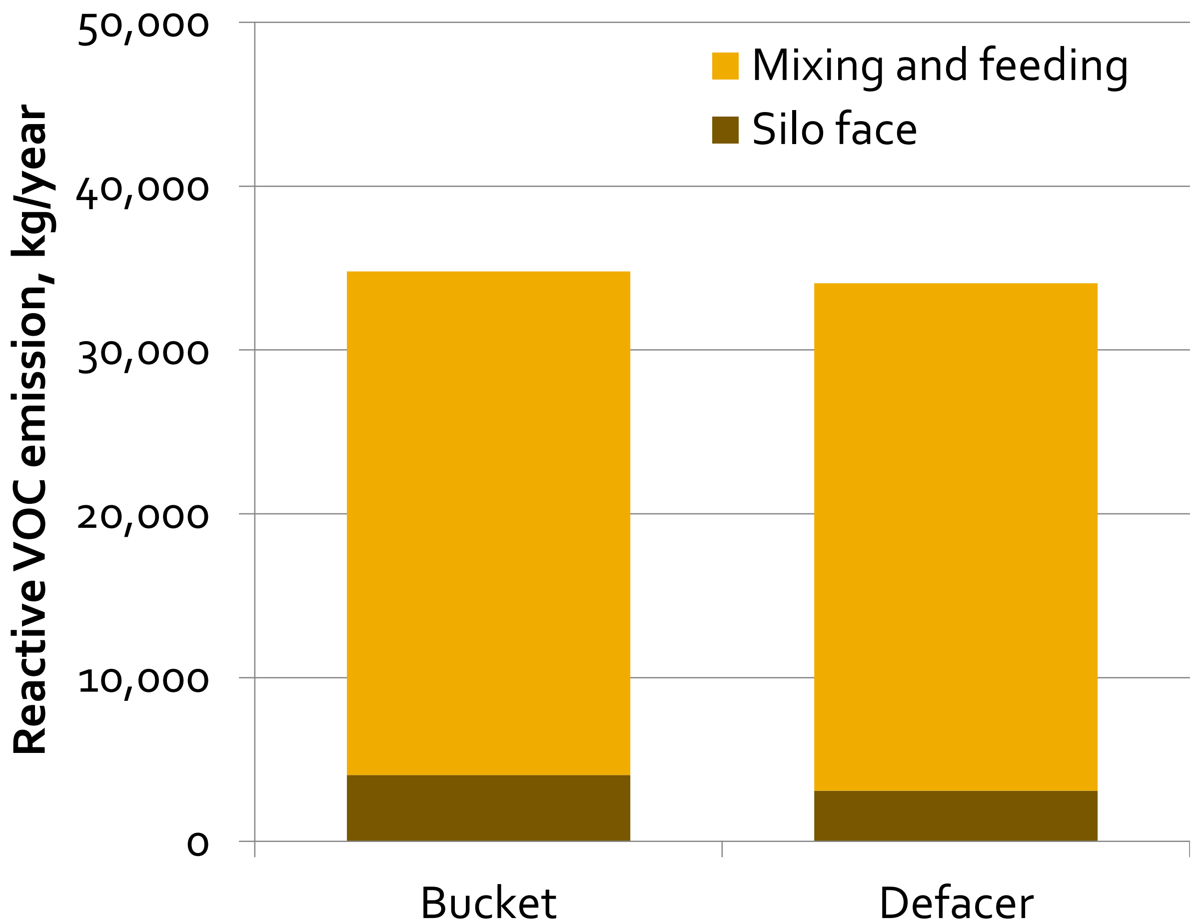
Silo Type


Reactive VOC emission, kg/year
50,000
40,000
30,000
20,000
10,000
0
Mixing and feeding
Silo face
Pile
Bunker
Bags

Packing Density



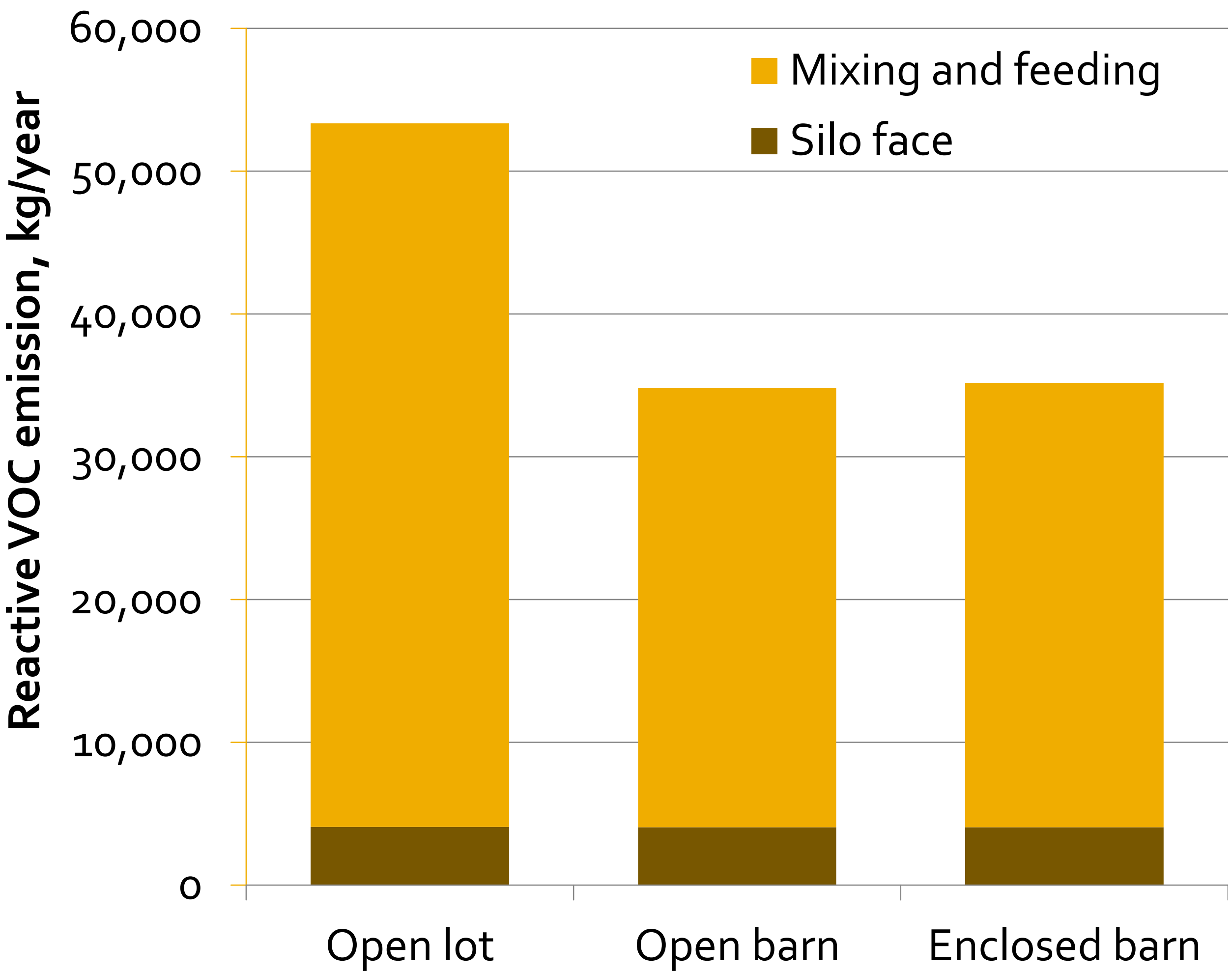
De-facing



Reactive VOC emission, kg/year
50,000
40,000
30,000
20,000
10,000
0
Mixing and feeding
Silo face
Bucket
Defacer

DEERE

Feeding Site



In Summary – Main Findings

Main Findings

- The four main phases of silage production, storage, and use are distinctively different from each other and addressing only one phase via mitigation, might likely lead to emissions downstream.

Main Findings

- It is apparent that the most effective VOC mitigation efforts are those that minimize the air exposure time of freshly extracted- as well as freshly mixed feed to the atmosphere (e.g., silage face and feed-lanes).

Main Findings

- A process based VOC model was developed and validated with monitoring data.
- Simulations of a representative dairy farm in California indicate that most of the reactive VOC emissions occur from feed lying in feed lanes during feeding rather than from the storage pile.
- This implies that mitigation efforts should focus on reducing emissions during feeding.

Our Recent Silage Literature

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- Hafner, S.D., R. B. Franco, L. Kung Jr, C.A. Rotz, and F.M. Mitloehner. 2014. Potassium sorbate reduces production of ethanol and 2 esters in corn silage. *Journal of Dairy Science.* 97:7870-7878.